

# CHAPTER 3

## PRINCIPLES OF FLIGHT

Man has always wanted to fly. Legends from the very earliest times bear witness to this wish. Perhaps the most famous of these legends is the Greek myth about a father and son who flew with wings made of wax and feathers. It was not, however, until the successful flight by the Wright Brothers at Kitty Hawk, North Carolina, that the dream of flying became a reality. Since the flight at Kitty Hawk, aircraft designers have spent much time and effort in developing that first crude flying machine into the modern aircraft of today. To understand the principles of flight, you must first become familiar with the physical laws affecting aerodynamics.

### LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Identify the physical laws of aerodynamics, to include Newton's laws of motion and the Bernoulli principle.
2. Recognize the terms used to describe the various parts of an airfoil section.
3. Identify the terms used in airflow lift generation.
4. Recognize the four primary forces acting on an aircraft.
5. Identify the three axes of rotation and the terms relative to the aircraft's rotation about these axes.
6. Recognize the difference in aerodynamic principles that apply to fixed- and rotary-wing aircraft.

### PHYSICAL LAWS AFFECTING AERODYNAMICS

Aerodynamics is the study of the forces that let an aircraft fly. You should carefully study the principles covered here. Whether your job is to fly the aircraft or to maintain it, you should know why and how an aircraft flies. Knowing why and how lets you carry out your duties more effectively.

#### Laws Of Motion

Motion is the act or process of changing place or position. Simply put, motion is movement. An object may be **in motion in relation** to one object and **motionless in relation** to another. For example, a person sitting in an aircraft flying at 200 miles per hour (mph) is at rest or motionless in relation to the aircraft. However, the person is in motion in relation to the air or the earth. Air has no force or power other than pressure when it is motionless. When air is moving, its force becomes apparent. A moving object in motionless air has a force exerted on it as a result of its own motion. It makes no difference in the effect whether an object is moving in relation to the air or the air is moving in relation to the object. The following information explains some basic laws of motion.

#### Newton's First Law Of Motion

According to Newton's first law of motion (inertia), an object at rest will remain at rest, or an object in motion will continue in motion at the same speed and in the same direction, until an outside force acts on it. For an aircraft to taxi or fly, a force must be applied to it. It will remain at rest without an outside force. Once the aircraft is moving, another force must act on it to bring it to a stop. It will continue in motion without an outside force. This willingness of an object to remain at rest or to continue in motion is referred to as inertia.

## Newton's Second Law of Motion

The second law of motion (force) states that if an object moving with uniform speed is acted upon by an external force, the change of motion (acceleration) will be directly proportional to the amount of force and inversely proportional to the mass of the object being moved. The motion will take place in the direction in which the force acts. Simply stated, this means that an object being pushed by 10 pounds of force will travel faster than it would if it were pushed by 5 pounds of force. A heavier object will accelerate more slowly than a lighter object when an equal force is applied.

## Newton's Third Law of Motion

The third law of motion (action and reaction) states that for every action (force) there is an equal and opposite reaction (force). This law can be demonstrated with a balloon. If you inflate a balloon with air and release it without securing the neck, as the air is expelled the balloon moves in the opposite direction of the air rushing out of it. *Figure 3-1* shows this law of motion.

## Bernoulli's Principle

Bernoulli's principle (*Figure 3-2*) states that when a fluid flowing through a tube reaches a constriction or narrowing of the tube, the speed of the fluid passing through the constriction is increased and its pressure is decreased.

## AIRFOIL

An airfoil is defined as that part of an aircraft that produces lift or any other desirable aerodynamic effect as it passes through the air. The wings and the propeller blades of a fixed-wing aircraft and the rotor blades of a helicopter are examples of airfoils.

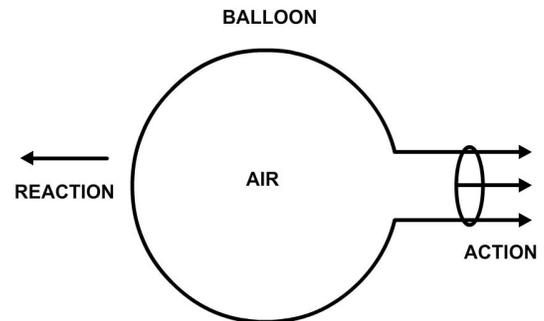


Figure 3-1 — Newton's third law of motion.

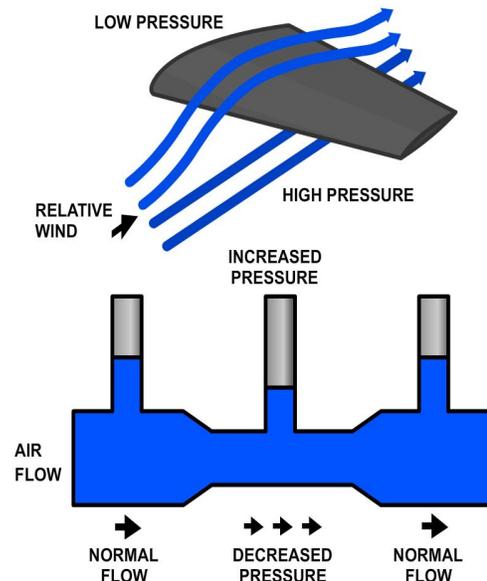
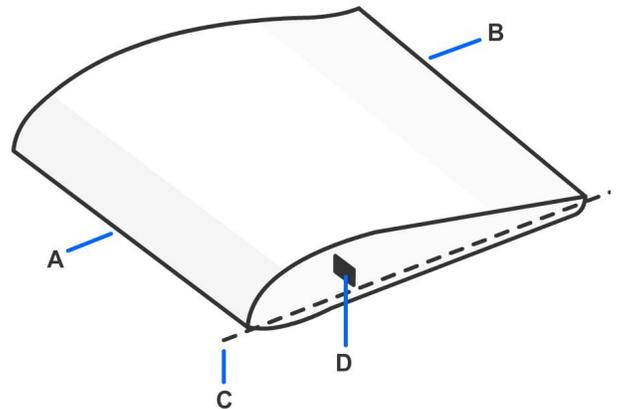


Figure 3-2 — Bernoulli's principle.

## AIRFOIL TERMINOLOGY

The shape of an airfoil and its relationship to the airstream are important. The following are common terms that you should understand before you learn about airfoils.

- Leading edge—the front edge or surface of the airfoil (*Figure 3-3*).
- Trailing edge —the rear edge or surface of the airfoil (*Figure 3-3*).
- Chord line —an imaginary straight line from the leading edge to the trailing edge of an airfoil (*Figure 3-3*).
- Camber —the curve or departure from a straight line (chord line) from the leading edge to the trailing edge of the airfoil (*Figure 3-3*).
- Relative wind —the direction of the airstream in relation to the airfoil (*Figure 3-4*).
- Angle of attack —the angle between the chord line and the relative wind (*Figure 3-4*).

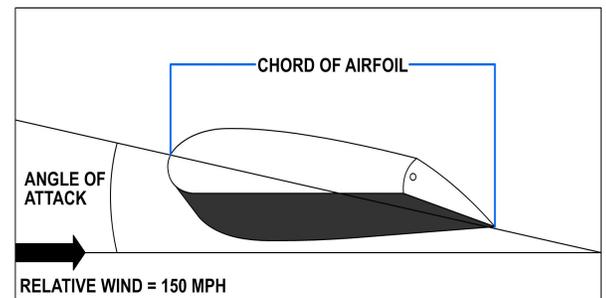


A. Leading Edge      C. Chord Line  
B. Trailing Edge      D. Chamber

**Figure 3-3 — Airfoil terminology.**

## Airflow Around An Airfoil

The generation of lift by an airfoil depends on the airfoil's ability to create a special airflow in the airstream. This airflow develops the lifting pressure over the airfoil surface. The effect is shown in *Figure 3-5*, which shows the relationship between lift and Bernoulli's principle. As the relative wind strikes the leading edge of the airfoil, the flow of air is split. A portion of the relative wind is deflected upward and aft, and the rest is deflected downward and aft. Since the upper surface of the airfoil has camber to it, the flow over its surface is disrupted. This disruption causes a wavelike effect to the airflow. The lower surface of the airfoil is relatively flat. The airflow across its surface is not disrupted. Lift is accomplished by this difference in the airflow across the airfoil.



**Figure 3-4 — Angle of attack.**

The shaded area of *Figure 3-5* shows a low-pressure area on the airfoil's upper surface. This low-pressure area is caused by the air that is disrupted by the camber of the airfoil, and it is the key to lift. There is less pressure on the top surface of the airfoil than there is on the lower surface. The air pressure pushes upward on the lower surface. This difference in pressure causes the airfoil to rise. You know that lift is developed by the difference between the air pressure on the upper and lower surfaces of the airfoil. As long as there is less pressure on the upper surface and more pressure on the lower surface of an airfoil, an aircraft has lift. Lift is one of the forces affecting flight.

## FORCES AFFECTING FLIGHT

An aircraft in flight is in the center of a continuous battle of forces. The conflict of these forces is the key to all maneuvers performed in the air. There is nothing mysterious about these forces—they are definite and known. The direction in which each acts can be calculated. The aircraft is designed to take advantage of each force. These forces are lift, weight, thrust, and drag.

### Lift

Lift is the force that acts in an upward direction to support the aircraft in the air. It counteracts the effects of weight. Lift must be greater than or equal to weight if flight is to be sustained.

### Weight

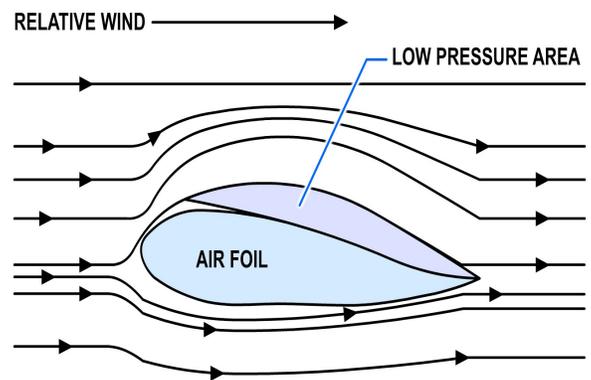
Weight is the force of gravity acting downward on the aircraft and everything in the aircraft, such as crew, fuel, and cargo.

### Thrust

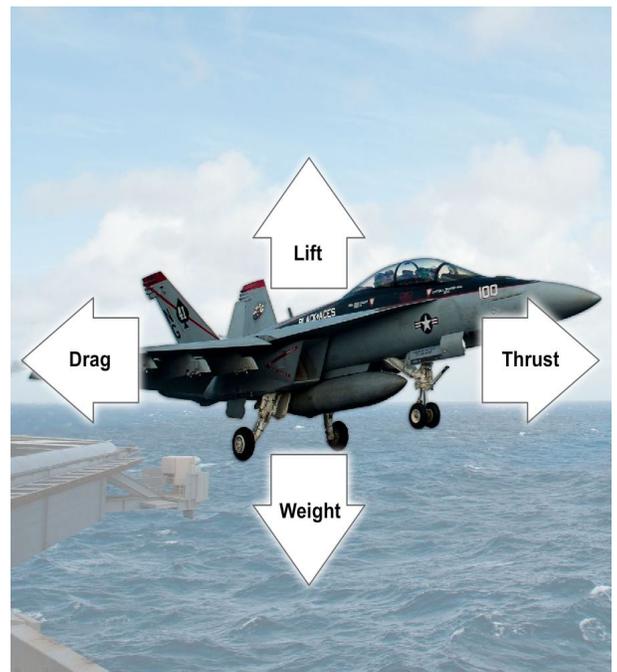
Thrust is the force developed by the aircraft's engine. It acts in the forward direction. Thrust must be greater than or equal to the effects of drag for flight to begin or to be sustained.

### Drag

Drag is the force that tends to hold an aircraft back. Drag is caused by the disruption of the airflow about the wings, fuselage (body), and all protruding objects on the aircraft. Drag resists motion as it acts parallel and in the opposite direction in relation to the relative wind. *Figure 3-6* shows the direction in which each of these forces acts in relation to an aircraft. Up to this point, you have learned the physical laws of aerodynamics, airfoils, and the forces affecting flight. To fully understand flight, you must learn about the rotational axes of an aircraft.



**Figure 3-5 — Airflow across an airfoil.**



**Figure 3-6 — Forces affecting flight.**

## ROTATIONAL AXES

Any vehicle, such as a ship, a car, or an aircraft, is capable of making three primary movements (roll, pitch, and yaw). The vehicle has three rotational axes that are perpendicular (90 degrees) to each other. These axes are referred to by their direction—longitudinal, lateral, and vertical. Perhaps the most descriptive reference is by what action takes place about a given axis or pivot point—roll, pitch, and yaw.

### Longitudinal Axis

The longitudinal axis is the pivot point about which an aircraft rolls. The movement associated with roll is best described as the movement of the wing tips (one up and the other down). *Figure 3-7* shows this movement. This axis runs fore and aft through the length (nose to tail) of the aircraft. This axis is parallel to the primary direction of the aircraft. The primary direction of a fixed-wing aircraft is always forward. *Figure 3-8* shows the longitudinal axis.

### Lateral Axis

The lateral axis is the pivot point about which the aircraft pitches. Pitch can best be described as the up and down motion of the nose of the aircraft. *Figure 3-7* shows this movement. The pitch axis runs from the left to the right of the aircraft (wing tip to wing tip). It is perpendicular to and intersects the roll axis. *Figure 3-8* shows the pitch axis and its relationship to the roll axis.

### Vertical Axis

The vertical axis runs from the top to the bottom of an aircraft. It runs perpendicular to both the roll and pitch axes. The movement associated with this axis is yaw. Yaw is best described as the change in aircraft heading to the right or left of the primary direction of an aircraft. *Figure 3-7* shows this movement. Assume you are walking from your work space to an aircraft located 100 feet away. You are trying to walk there in a straight line but are unable to do so because there is a strong wind blowing you off course to your right. This movement to the right is yaw. The yaw axis is shown in *Figure 3-8*.

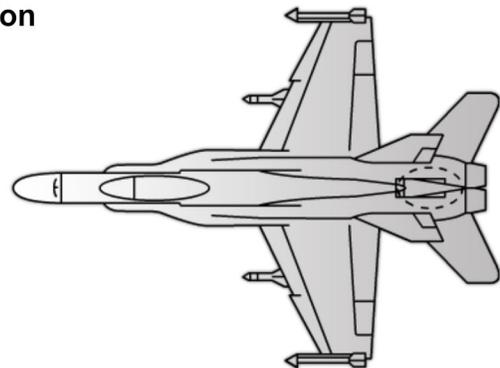
## FIXED-WING AND ROTARY-WING AIRCRAFT

A fixed-wing aircraft depends on forward motion for lift. A rotary-wing aircraft depends on rotating airfoils for lift. The airfoil sections of a fixed-wing aircraft are not symmetrical. The rotor blades of a

Roll Motion



Yaw Motion



Pitch Motion

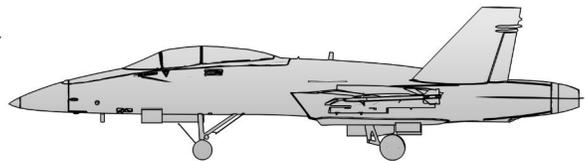


Figure 3-7 — Motion about the axes.

helicopter are symmetrical. These differences are important to you if you are to understand aerodynamic principles.

## Fixed-Wing Aircraft

You have learned about the physical laws and forces that affect flight, the airfoil, and the rotational axes of an aircraft. Now, let's apply these principles to a fixed-wing aircraft in flight. First, motion must exist. Motion is provided by the thrust developed by the engine of the aircraft. This is accomplished by the force exerted by the exhaust gases of a jet aircraft or by the action of the propeller blades on a propeller-driven aircraft. The thrust overcomes the force of inertia and, as the fixed-wing aircraft accelerates, the air flows by the wings. The relative wind striking the leading edge of the wings is split and flows across the upper and lower surfaces. The camber of the upper surface acts as a constriction, which speeds up the airflow and reduces the pressure of the air. The lower surface, being relatively flat, does not affect the speed or pressure of the air. There is lower air pressure on the upper surface of the wing than on the lower surface. The fixed-wing aircraft is lifted into the air.

Now that the aircraft is safely in the air, rotational axes come into play. If the nose of the aircraft is raised, the angle of attack changes. Changing the angle of attack causes the aircraft to pivot on its lateral or pitch axis. If you lower the right wing of the aircraft, the left wing rises. The aircraft moves about its longitudinal or roll axis. Assume that the aircraft is in a straight and level flight. There is a strong wind striking the aircraft's nose on the left side, pushing the nose to the right. This causes the tail of the aircraft to move to the left, and the aircraft is pivoting on its vertical or yaw axis. All of these forces are necessary for flight to begin or be sustained.

## Rotary-Wing Aircraft (Helicopters)

The same basic aerodynamic principles you read about earlier in this chapter apply to rotary-wing aircraft. The main difference between fixed-wing and rotary-wing aircraft is the way lift is achieved (*Figure 3-9*).

### Lift

The fixed-wing aircraft gets its lift from a fixed airfoil surface. The helicopter gets lift from rotating airfoils called rotor blades. The word helicopter comes from the Greek words meaning helical wing or rotating wing. A helicopter uses two or more engine-driven rotors from which it gets lift and propulsion.

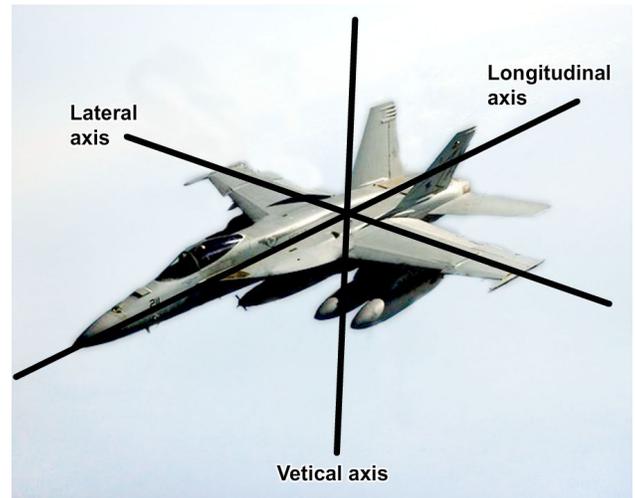


Figure 3-8 — Axes of an aircraft.

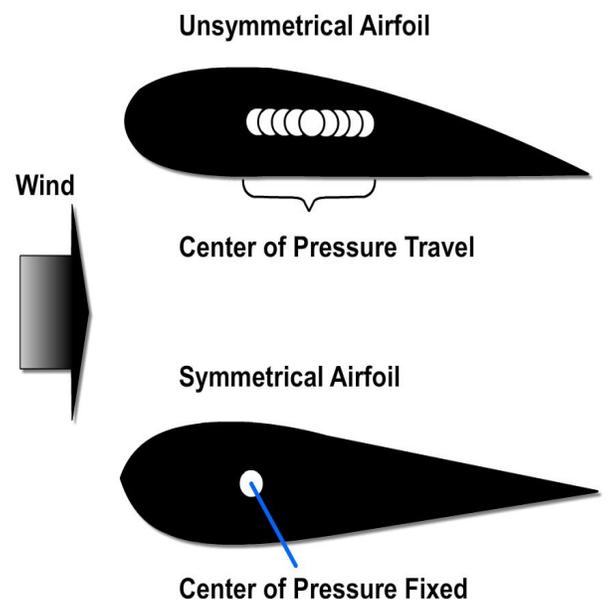


Figure 3-9 — Center of pressure.

The helicopter's airfoils are the rotor blades. The airfoils of a helicopter are perfectly symmetrical. This means that the upper and lower surfaces are shaped the same. This fact is one of the major differences between the fixed-wing aircraft's airfoil and the helicopter's airfoil. A fixed-wing aircraft's airfoil has a greater camber on the upper surface than on the lower surface. The helicopter's airfoil camber is the same on both surfaces. The symmetrical airfoil is used on the helicopter because the center of pressure across its surface is fixed. On the fixed-wing airfoil, the center of pressure moves fore and aft, along the chord line, with changes in the angle of attack. If this type of airfoil were used on a rotary-wing aircraft, it would cause the rotor blades to jump around (dive and climb) uncontrollably. With the symmetrical airfoil, this undesirable effect is removed. The airfoil, when rotated, travels smoothly through the air.

The main rotor of a helicopter consists of two or more rotor blades. Lift is accomplished by rotating the blades through the air at a high rate of speed. Lift may be changed by increasing the angle of attack or pitch of the rotor blades. When the rotor is turning and the blades are at zero angle (flat pitch), no lift is developed. This feature provides the pilot with complete control of the lift developed by the rotor blades.

### **Directional Control**

A pilot controls the direction of flight of the helicopter by tilting the main rotor. If the rotor is tilted forward, the force developed by the rotor is directed downward and aft. Now, apply Newton's third law of motion (action and reaction). Lift will be developed in an upward and forward direction, and the helicopter will tend to rise and move forward. From this example, you should realize that a pilot can move a helicopter forward or rearward, or to the right or left, simply by tilting the main rotor in the desired direction.

*Figure 3-10* points out another major difference between fixed-wing and rotary-wing aircraft. The fixed-wing aircraft cannot move up or down or right or left without forward movement. Remember, a fixed-wing aircraft's primary direction is forward. However, a helicopter can move in any direction, with or without forward movement.

### **Hovering**

Hovering is defined as maintaining a position above a fixed spot on the ground. A helicopter has the ability to remain in one spot in the air with little or no movement in any direction. This feat is done by equalizing all the forces acting on the helicopters (lift, drag, weight, and thrust). This action also allows a helicopter to take off or land without a runway. This is another advantage the rotary-wing aircraft has over the fixed-wing aircraft.

### **Torque Reaction**

As the helicopter's main rotor turns in one direction, the body (fuselage) of the helicopter tends to rotate in the opposite direction (Newton's third law). This is known as torque reaction. In a single main rotor helicopter, the usual way of getting rid of torque reaction is by using a tail rotor (anti-torque rotor). This rotor is mounted vertically on the outer portion of the helicopter's tail section (*Figure 3-10*). The tail rotor produces thrust in the opposite direction of the torque reaction developed by the main rotor. *Figure 3-10* shows the manner in which torque reaction is eliminated in a single main rotor helicopter.

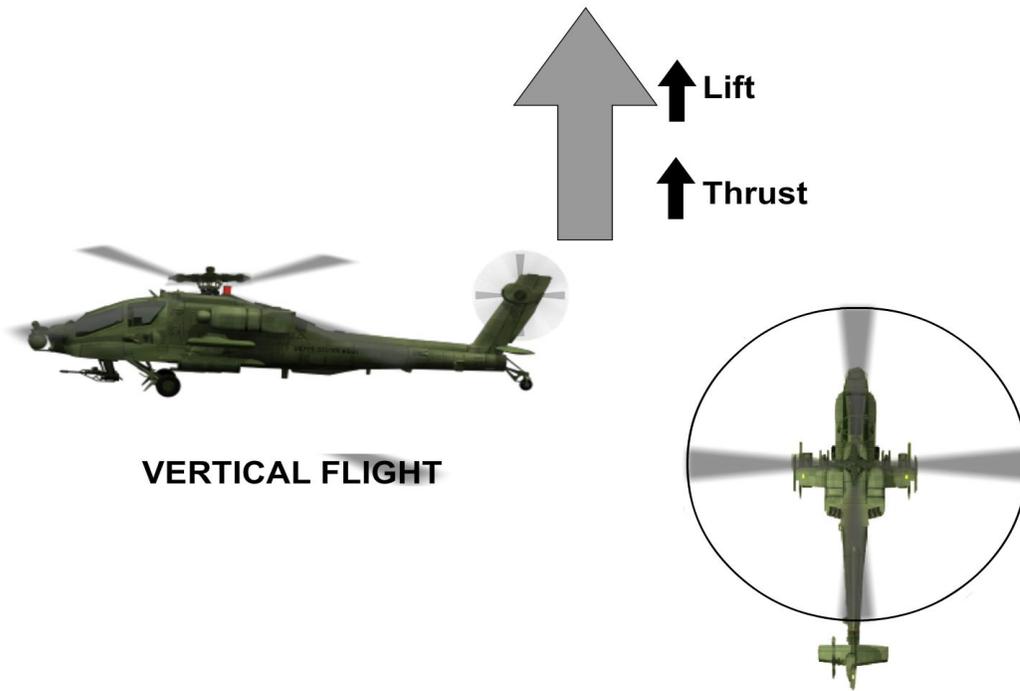


Figure 3-10 — Directional flight attitudes and torque reaction.

# End of Chapter 3

## Principles of Flight

### Review Questions

3-1. What is Newton's first law of motion?

- A. Action and reaction
- B. Force
- C. Inertia
- D. gravity

3-2. Which of the following is Newton's second law motion?

- A. Action and reaction
- B. Force
- C. Inertia
- D. gravity

3-3. Which of the following is Newton's third law motion?

- A. Action and reaction
- B. Force
- C. Inertia
- D. gravity

3-4. Which of the following is Bernoulli's principle?

- A. For every action there is an equal and opposite reaction.
- B. An object moving with uniform speed is acted upon by an external force; the change of motion will be directly proportional to the amount of force.
- C. An object at rest will remain at rest.
- D. When a fluid flowing through a tube reaches a constriction or narrowing of the tube, the speed of the fluid passing through the constriction is increased and its pressure is decreased.

3-5. What is the front edge of an airfoil called?

- A. Camber
- B. Chord
- C. Leading
- D. Trailing

3-6. What is the rear edge of an airfoil called?

- A. Camber
- B. Chord
- C. Leading
- D. Trailing

- 3-7. What is the name for the imaginary line from the leading edge to the trailing edge of an airfoil?
- A. Camber
  - B. Chord
  - C. Leading
  - D. Trailing
- 3-8. What is the name for the curve or departure of a straight line from the leading edge to the trailing edge of the airfoil?
- A. Camber
  - B. Chord
  - C. Leading
  - D. Trailing
- 3-9. What is the direction of the airstream in relation to the airfoil known as?
- A. Angle of attack
  - B. Camber
  - C. Relative wind
  - D. Trailing edge
- 3-10. What is the angle between the chord line and the relative wind known as?
- A. Angle of attack
  - B. Camber
  - C. Relative wind
  - D. Trailing edge
- 3-11. What is the force that acts in an upward direction called?
- A. Drag
  - B. Lift
  - C. Thrust
  - D. Weight
- 3-12. What is the force developed by the aircraft's engine?
- A. Drag
  - B. Lift
  - C. Thrust
  - D. Weight
- 3-13. What is the force acting downward on the aircraft?
- A. Drag
  - B. Lift
  - C. Thrust
  - D. Weight

3-14. What is the force that tends to hold an aircraft back?

- A. Drag
- B. Lift
- C. Thrust
- D. Weight

3-15. What resists motion as it acts parallel and in the opposite direction in relation to the relative wind?

- A. Drag
- B. Lift
- C. Thrust
- D. Weight

3-16. What axis runs from the top to the bottom of an aircraft?

- A. Lateral
- B. Longitudinal
- C. Pitch
- D. Vertical

3-17. What axis is the pivot point about which an aircraft rolls?

- A. Lateral
- B. Longitudinal
- C. Pitch
- D. Vertical

3-18. What axis is the pivot point about which an aircraft pitches?

- A. Lateral
- B. Longitudinal
- C. Pitch
- D. Vertical

3-19. From what type of surface does a fixed-wing aircraft get its lift from?

- A. Fixed
- B. Rotating
- C. Smooth
- D. Rough

3-20. From what type of surface does a helicopter get its lift from?

- A. Fixed
- B. Rotating
- C. Smooth
- D. Rough

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